Composition of the dragonfly fauna at different altitudes in Bhutan based on larval samples

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Abstract

In 2020 thirty sites with running water and ten sites with standing water were sampled for both adult and larval odonates in both the pre-monsoon and the post-monsoon period. This sampling was performed along an altitudinal gradient from 500-3000 m in Punakha and Wangduephodrang provinces of Bhutan. The results of the running water sites showed that there are clear differences between the overall abundance, species diversity and species associations at different altitudes. Furthermore, a clear difference was observed in the number of larvae collected in running water in the post-monsoon (404 specimens) and the pre-monsoon (654 specimens) periods, with five species being clearly more abundant in the pre-monsoon and one species being more abundant in the post-monsoon period.

Key words: Bhutan, monsoon, elevation, distribution, Himalaya.

Introduction

Bhutan is a small country in the eastern Himalaya region of south Asia renowned for its diverse and well-preserved biodiversity. It lies at the transition zone between the Oriental and the Palearctic region. At present 123 species of dragonflies and damselflies are known from Bhutan and it is likely that further field work will show that at least 150 species occur in the country (Gyeltshen et al., 2017; Gyeltshen, Kalkman & Orr, 2017; Gurung et al., 2021). Only a few species of Odonata are found above 3000 m a.s.l. (Gyeltshen, Kalkman and Orr, 2017). Knowledge of Odonata in Bhutan has greatly increased in the past decade due to the cooperation of the National Biodiversity Centre, Serbithang with the Dutch Naturalis Biodiversity Center resulting in the start of the Bhutan Invertebrate Biodiversity Project in 2014 (Gyeltshen & Kalkman, 2017). Odonata was among the five focal groups identified for this study, with the result being various papers published in the last couple of years (Kalkman & Gyeltshen, 2016; Gyeltshen & Kalkman, 2017; Gyeltshen, et al., 2017; Gyeltshen, 2020; Gurung, et al., 2021). Despite this increase in knowledge

little is known of the altitudinal distribution of dragonfly communities in the eastern Himalayan region. An overview of elevational range of species occurring in Nepal, largely based on information on adults was published by Vick (1989). The only paper with a focus on dragonflies in which the larval communities were studied along an altitudinal gradient in this part of the Himalayan range is Mahato & Edds (1993). They used data on larvae collected at 40 sites at the Gandaki river in central Nepal, collected between 50 and 1189 m a.s.l. with one site at 2560 m a.s.l. In 2020 the first author performed field work on aquatic habitats in Bhutan to assess odonate biodiversity in terms of breeding habitats. Emphasis was put on collecting data of species of running water over a large altitudinal gradient. The results are presented here.

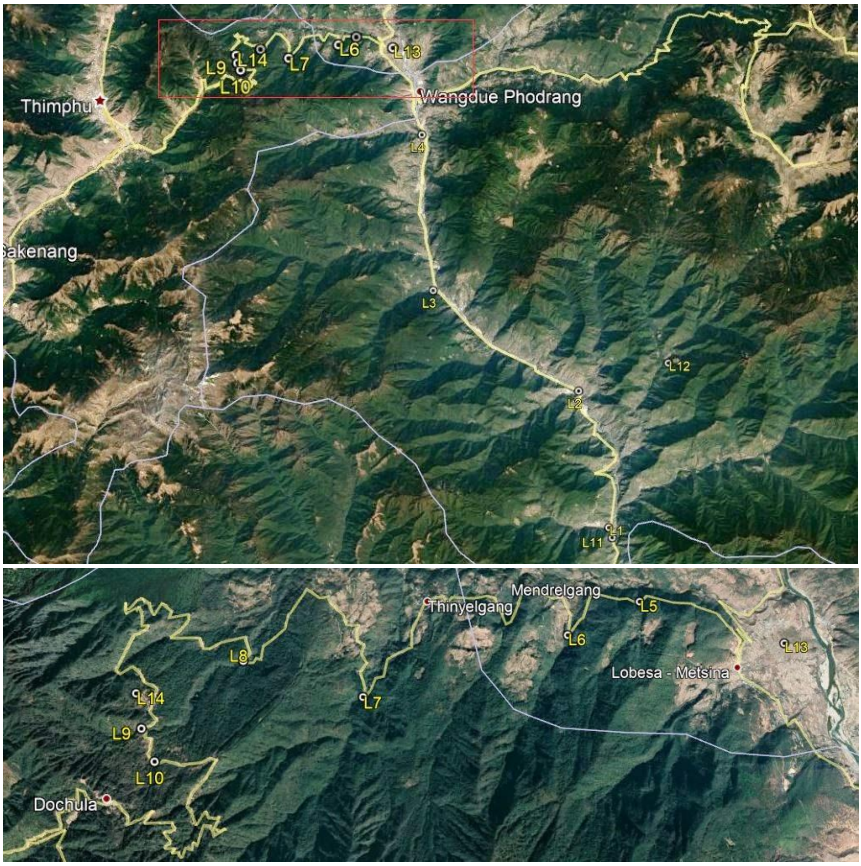

Figure 1a, b. Maps of Punakha and Wangduephodrang provinces in Bhutan showing the location of the 14 sampling localities.

Material and methods

In 2020 the dragonfly fauna of a total of 40 sites at 14 different localities (L1-L14 in figure 1) was studied in the Punakha and Wangduephodrang provinces of Bhutan. Thirty of these were running water sites and 10 were standing water. The thirty running water sites were divided over 10 different streams with clusters of three sites on every stream. These three sites (lower, middle and upper sites) were each 100m long and separated from each other by an intervening stretch of 100m, so in total forming a stretch of 500 m. The ten standing water sites were divided over four different localities with sites 32-35 belonging to different sections of Adha lake and sites 37-40 to different sections of a natural lake at Lamperi. The sites sampled along the shore at standing water were 50 m long. Each of these sites were visited during the pre-monsoon period (15.iv.2020 to 15.vi.2020) and during the post-monsoon period (1.x.2020 to 31.xi.2020). Adult dragonflies were photographed and/or collected but as no field work was conducted during

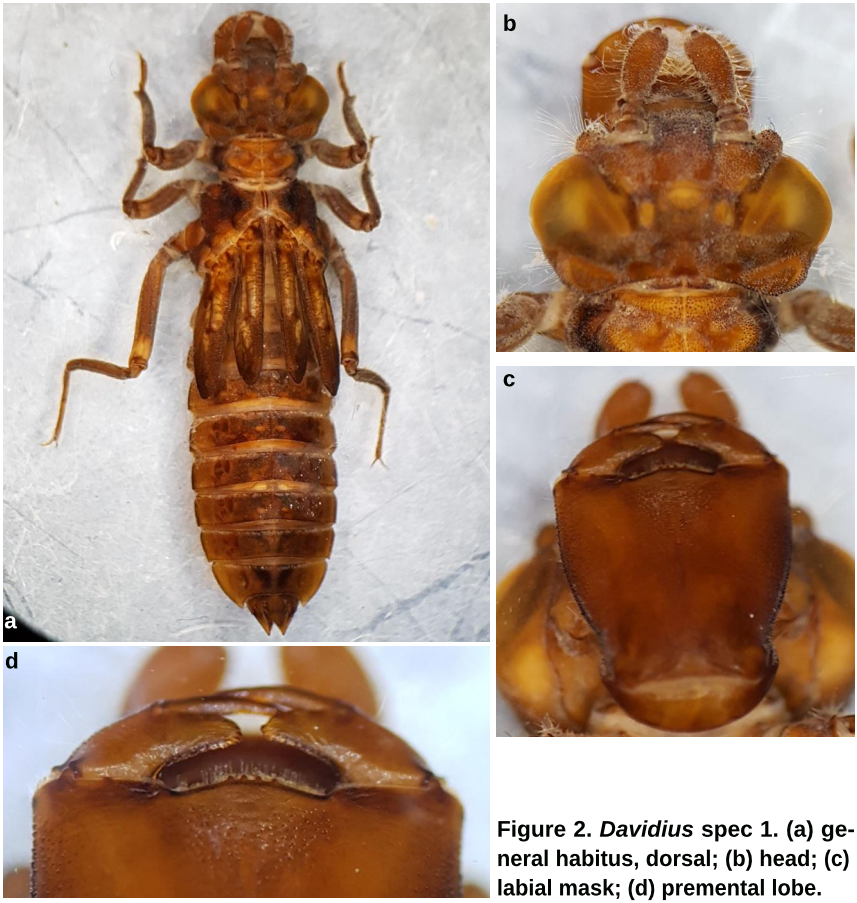

Figure 2. *Davidius* spec 1. (a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.

summer due to Covid restrictions the list of adult dragonflies recorded is incomplete. Sampling visits lasted two hours per site—as many larvae as possible were collected and the sampling was done at every 10 m at each site of a 100 m (running water) or 50 m (standing water) site. All larvae were collected and put in vials with 70% alcohol. Both the collected adults and larvae are stored in the collection of College of Natural Resources, Punakha and the National Biodiversity Centre, Serbithang (Bhutan).

Except to the key to the families by Nesemann et al. (2011) no general key to the species or genera for the larva found in the Himalayan region is available, hence for identification we consulted numerous papers (see Kalkman et al., 2020 for an overview of larval description from the South Asia). Four species of Gomphidae were found commonly but two could not be identified beyond genus level, and in one case not even to genus. In order to facilitate future identification of these records to species level we provide short descriptions of each, detailing the characters we used to separate them.

Davidius spec 1 (Fig 2). Several species of *Davidius* occur in the region and it is at present not possible to identify their larvae to species level. Characterization: Third antennal segment oval shaped and about twice as long as broad, flattened and bent inwards. Head between base of antennae and eyes with a prominent knob like protrusion. Apical margin of prementum, gently convex with four conspicuous black teeth; labial palps bluntly rounded. Burrowing hooks (blunt) present on fore and middle tibae. No dorsal spines or knobs on dorsum of abdomen, segment 7 (very small) and segments 8-9 with short lateral hooks. Anal pyramid about as long as wide. Wing sheaths parallel.

Davidius spec 2 (Fig 3). Several species of *Davidius* occur in the region and it is at present not possible to identify their larvae to species level. Characterization: Third antennal segment, flat, oval shaped and broader than long, covering front of head. Head between base of antennae and eyes with a prominent knob like protrusion. Apical margin of prementum strongly convex, with about 14 conspicuous black teeth; labial palps bluntly rounded. Burrowing hooks (sharply pointed) present on fore and middle tibae. No dorsal spines or knobs on dorsum of abdomen, lateral spines absent. Anal pyramid about as long as wide. Wing sheaths parallel.

Perissogomphus stevensi (Fig 4). The larva of this genus is still undescribed and the identification is based on preliminary DNA results. Characterization: Third antennal segment long, almost straight, slightly flattened. Apical margin of prementum convex, with >30 small black teeth; labial palps bluntly rounded. Blunt dorsal knobs present on segment 2-9, short lateral spines present on segment 7-9; large burrowing hooks present on fore and middle tibiae. Anal pyramid longer than wide. Wing sheaths diverging.

Gomphidae genus indet. (Fig 5). Based on its diverging wing sheaths and distribution, this is most likely *Scalmogomphus* or *Lamelligomphus*. Characterization: Third antennal segment long, bent inwards gradually expanding reaching its broadest point at two-thirds of the segment, its ventral point flattened. Apical margin of prementum weakly convex, with about 16 small black teeth; labial palps bluntly rounded. Blunt dorsal knobs present on segment 2-9, short lateral spines present on segment 9; small burrowing hooks on fore and middle tibiae small. Anal pyramid longer than wide. Wing sheaths diverging.

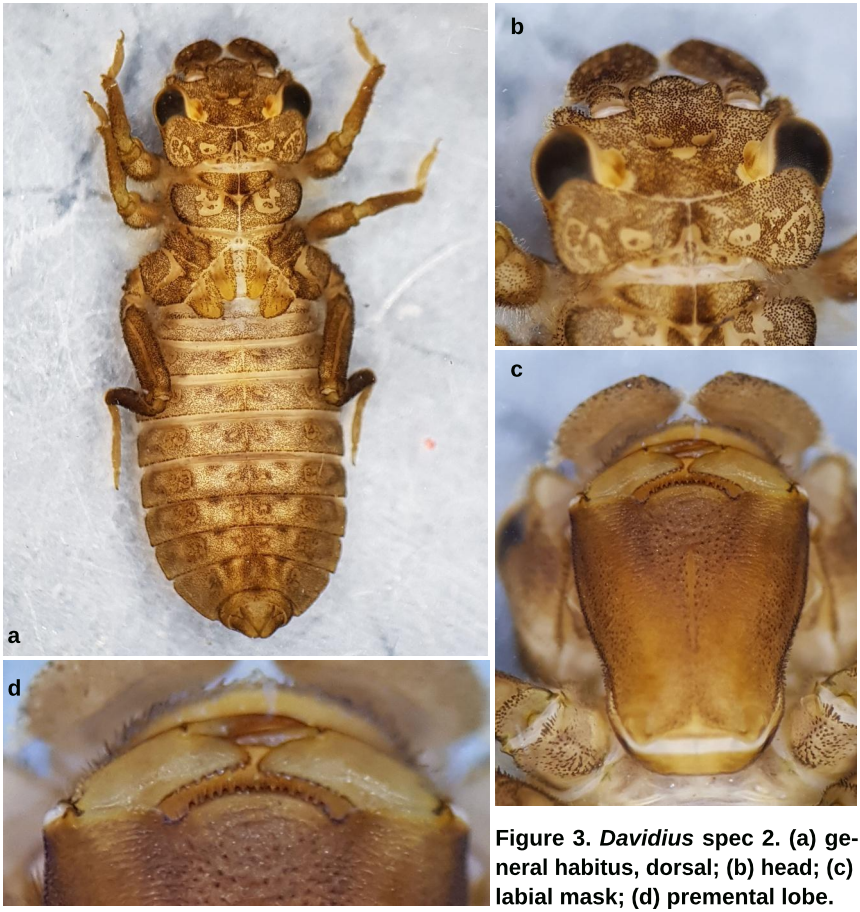

Figure 3. *Davidius* spec 2. (a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.

List of localities (L) and sites

(L1, site 1) (Fig. 6) Wangduephodrang District, Taksha; lower reach of the stream beside gravel and sand deposit (27.171084°N, 90.064520°E, 509 m a.s.l.) 16.iv.2020, 23.xi.2020. **(L1, site 2)** Wangduephodrang District, Taksha; middle reach of the stream beside human settlement with dumped waste (27.171346°N, 90.060634°E, 536 m a.s.l.) 17.iv.2020, 24.xi.2020. **(L1, site 3)** Wangduephodrang District, Taksha; upper reach with large rocks stacked on the bank (27.171565°N, 90.056923°E, 564 m a.s.l.) 20.iv.2020, 26.xi.2020.

(L2, site 4) Wangduephodrang District, Kamichu; lower reach with algal growth, dust covering the leaves and some plastic and paper litter (27.270752°N, 90.037214°E, 640 m a.s.l.) 19.iv.2020, 17.xi.2020. **(L2, site 5)** Wangduephodrang District, Kamichu; middle

Figure 4. ***Perissogomphus stevensi*** **(a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.**

reach with algal growth; earth excavated beside the bank and dust covering leaves (27.269575°N, 90.035763°E, 641 m a.s.l.) 21.iv.2020, 20.xi.2020. **(L2, site 6)** Wangduephodrang District, Kamichhu; upper reach with algal growth (27.268347°N, 90.034366°E, 641 m a.s.l.) 21.iv.2020, 21.xi.2020.

(L3, site 7) Wangduephodrang District, Rurichhu; lower reach of the stream with flow controlled from the reservoir dam and some plastic and paper litter (27.342048°N, 89.915077°E, 931 m a.s.l.) 18.v.2020, 9.ix.2020. **(L3, site 8)** Wangduephodrang District, Rurichhu;

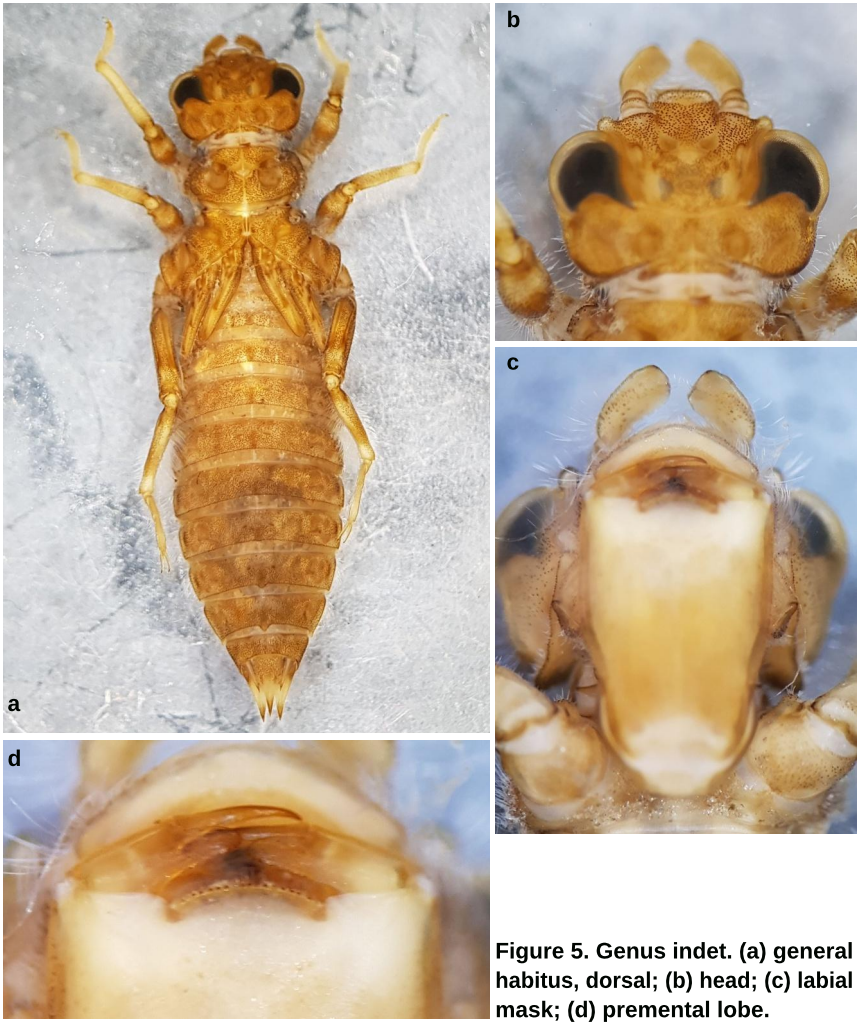

Figure 5. Genus indet. (a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.

middle reach of the stream with flow controlled from the reservoir dam; some plastic and paper litter and animal dung present (27.341171°N, 89.913172°E, 989 m a.s.l.) 19.v.2020, 12.xi.2020. **(L3, site 9)** Wangduephodrang District, Rurichhu; upper reach of the stream with flow controlled from the reservoir dam and some plastic and paper litter (27.340457°N, 89.911867°E, 1071 m a.s.l.) 19.v.2020, 12.xi.2020.

(L4, site 10) (Fig. 7) Wangduephodrang District, Hesothanka; lower reach of the stream with rapid current; some plastic and paper litter and settlements within 50 m (27.456273°N, 89.902611°E, 1231 m a.s.l.) 26.v.2020, 8.xi.2020. **(L4, site 11)** Wang-

Figure 6. Habitat at site 1 showing the impact of road construction. Larvae of *Perissogomphus stevensi*, *Gomphidae* spec and *Macromia moore*i were collected here.

Figure 7. Habitat at site 4. At this site the natural bank site vegetation was largely destroyed and some plastic and paper litter were found in the water. Here larvae of *Bayadera* spec, *Perissogomphus stevensi* and *Macromia moorei* were collected.

duephodrang District, Hesothanka; middle reach of the stream with some plastic and paper litter (27.456030°N, 89.900604°E, 1240 m a.s.l.) 27.v.2020, 9.xi.2020. **(L4, site 12)** Wangduephodrang District, Hesothanka; upper reach of the stream (27.456098°N, 89.899032°E, 1261 m a.s.l.) 1.v.2020, 13.xi.2020.

(L5, site 13) Punakha District, Mendelgang; lower reach with water diverted resulting in irregular flow; overgrowth bush and plastic and paper litter (27.526618°N, 89.846681°E,

1613 m a.s.l.) 28.v.2020, 23.x.2020. **(L5, site 14)** Punakha District, Mendelgang; middle reach with dry bed (27.525007°N, 89.847273°E, 1646 m a.s.l.) 30.v.2020, 23.x.2020. **(L5, site 15)** Punakha District, Mendelgang; upper reach with dry bed (27.523096°N, 89.846717°E, 1712 m a.s.l.) 30.v.2020, 23.x.2020.

(L6, site 16) Punakha District, Mendelgang; lower reach with fallen tree along the brook and some plastic and paper litter (27.520715°N, 89.832620°E, 1588 m a.s.l.) 17.v.2020, 26.x.2020. **(L6, site 17)** Punakha District, Mendelgang; middle reach of the brook with animal trampling and dry land within 50m (27.518010°N, 89.831685°E, 1632 m a.s.l.) 21.v.2020, 28.x.2020. **(L6, site 18)** Punakha District, Mendelgang; upper reach of the brook with grass mat and overgrowing vegetation (27.516542°N, 89.830285°E, 1661 m a.s.l.) 21.v.2020, 28.x.2020.

(L7, site 19) Punakha District, Thinleygang; lower reach with stony brook; some plastic and paper litter (27.508373°N, 89.792520°E, 1934 m a.s.l.) 9.v.2020, 16.x.2020. **(L7, site 20)** Punakha District, Thinleygang; middle reach with fast running brook and water channelled into a large pipe (27.507038°N, 89.790558°E, 1986 m a.s.l.) 14.v.2020, 20.x.2020. **(L7, site 21)** Punakha District, Thinleygang; upper reach with fast running brook, some pipelines and concrete water tank (27.505191°N, 89.789944°E, 2068 m a.s.l.) 15.v.2020, 20.x.2020.

(L8, site 22) Punakha District, Menchuna; lower reach with fast running brook with over growth of *Aconogonum molle* and some plastic and paper litter (27.513843°N, 89.769893°E, 2250 m a.s.l.) 24.v.2020, 16.x.2020. **(L8, site 23)** Punakha District, Menchuna; middle reach with fast running brook and some plastic and paper litter (27.512609°N, 89.768034°E, 2266 m a.s.l.) 27.v.2020, 18.x.2020. **(L8, site 24)** Punakha District, Menchuna; upper reach with stony brook (27.512833°N, 89.765819°E, 2290 m a.s.l.) 27.v.2020, 18.x.2020.

(L9, site 25) Punakha District, Lamperi; lower reach with stony brook; plastic and paper litter and over growth of *Aconogonum molle* (27.502119°N, 89.752943°E, 2683 m a.s.l.) 29.v.2020, 7.x.2020. **(L9, site 26)** Punakha District, Lamperi; middle reach of the stony brook (27.500993°N, 89.751264°E, 2810 m a.s.l.) 30.v.2020, 9.x.2020. **(L9, site 27)** Punakha District, Lamperi; upper reach of the stony brook (27.499951°N, 89.749565°E, 2890 m a.s.l.) 30.v.2020, 9.x.2020.

(L10, site 28) (Fig. 8) Punakha District, Lamperi; lower reach of the stony brook with much plastic and paper litter (27.496874°N, 89.755801°E, 2736 m a.s.l.) 2.vi.2020, 7.x.2020. **(L10, site 29)** Punakha District, Lamperi; middle reach of a stony brook (27.494850°N, 89.755140°E, 2787 m a.s.l.) 5.vi.2020, 8.x.2020. **(L10, site 30)** Punakha District; upper reach of a stony brook (27.494844°N, 89.754633°E, 2958 m a.s.l.) 5.vi.2020, 8.x.2020.

(L11, site 31) Wangduephodrang District, Taksha; stagnant water beside the road with abundance of macrophytes, *Nasturtium officinale* (27.163886°N, 90.067485°E, 476 m a.s.l.) 25.iv.2020, 28.xi.2020.

(L12, site 32) (Fig. 9) Wangduephodrang District, Adha; along north shoreline of natural lake (27.293414°N, 90.108940°E, 1254 m a.s.l.) 6.v.2020, 2.xi.2020. **(L12, site 33)** Wangduephodrang District, Adha; along west shoreline of natural lake (27.292216°N,

Figure 8. Habitat at site 10. Here larvae of *Anisopleura* spec, *Bayadera* spec, *Davidius* spec1, Gomphidae spec, *Perissogomphus stevensi* and *Macromia moorei* were collected.

Figure 9. Habitat at site 12. Here larvae of *Bayadera* spec, *Anotogaster/Neallogaster*, *Chlorogomphus* spec, *Davidius* spec1, Gomphidae spec, *Perissogomphus stevensi*, *Macromia moorei* were collected.

90.109160°E, 1236 m a.s.l.) 6.v.2020, 2.xi.2020. **(L12, site 34)** Wangduephodrang District, Adha; along south shoreline of natural lake (27.291748°N, 90.110073°E, 1217 m a.s.l.) 6.v.2020, 2.xi.2020. **(L12, site 35)** Wangduephodrang District, Adha; along east shoreline of natural lake (27.292823°N, 90.110026°E, 1260 m a.s.l.) 6.v.2020, 2.xi.2020.

(L13, site 36) Punakha District, Lobesa; artificial pool in orchard (27.520144°N, 89.876707°E, 1275 m a.s.l.) 10.vi.2020, 6.xi.2020.

(L14, site 37) Punakha District, Lamperi, along south shoreline of natural pond (27.507220°N, 89.752080°E, 2696 m a.s.l.) 7.vi.2020, 3.x.2020. **(L14, site 38)** Punakha District, Lamperi; along east shoreline of natural pond (27.507759°N, 89.752080°E, 2699 m a.s.l.) 7.vi.2020, 3.x.2020. **(L14, site 39)** Punakha District, Lamperi; along north shoreline of natural pond (27.507793°N, 89.751561°E, 2699 m a.s.l.) 7.vi.2020, 4.x.2020. (**L14, site 40**) Punakha District, Lamperi; along west shoreline of natural pond (27.507390°N, 89.751493°E, 2705 m a.s.l.) 7.vi.2020, 4.x.2020.

Results

A total of 95 specimens representing 29 species of dragonflies and damselflies were recorded as adults. In total 1210 larvae were collected belonging to 22 different species. Of these only seven can be assigned to a named species. One gomphid could not be assigned to genus.

List of species collected

The taxonomy follows that of (Kalkman et al., 2020).

Synlestidae

1. *Megalestes* sp.

(19) 3 larvae (9.v.2020) **(21)** 2 larvae (15.v.2020) **(21)** 3 larvae (20.x.2020).

Lestidae

2. *Indolestes cyaneus* (Selys, 1862)

(37) 3♂1♀ adults (7.vi.2020) **(38)** 1♂1♀ adults (7.vi.2020) **(38)** 1♂ adult (4.x.2020) **(39)** 1♂ adult (4.x.2020).

Calopterygidae

3. *Neurobasis chinensis* (Linnaeus, 1758)

(9) 1 larva (19.v.2020).

Chlorocyphidae

4. *Aristocypha* sp.

(9) 1♀ adult (19.v.2020).

5. *Paracypha unimaculata* (Selys, 1853)

(9) 1♂ adult (19.v.2020).

Euphaeidae

6. *Anisopleura lestoides* (Selys, 1853)

(2) 1♂ adult (17.iv.2020).

7. *Anisopleura* sp.

(7) 1 larva (18.v.2020) **(10)** 1 larva (26.v.2020) **(16)** 31 larvae (17.v.2020) **(17)** 25 larvae (21.v.2020) **(17)** 18 larvae (28.x.2020) **(18)** 2 larvae (21.v.2020) **(18)** 12 larvae (28.x.2020) **(31)** 1♂ adult (25.iv.2020) 1♀ teneral (17.iv.2020).

8. *Bayadera indica* (Selys, 1853)

(6) 1♂ adult (21.iv.2020) **(6)** 1♀ adult (21.iv.2020) **(9)** 1♂ adult (19.v.2020).

9. *Bayadera* sp.

(2) 1 larva (17.iv.2020) **(3)** 3 larvae (20.iv.2020) **(4)** 2 larvae (19.iv.2020) **(5)** 2 larvae (21.iv.2020) **(5)** 2 larvae (20.xi.2020) **(6)** 5 larvae (21.iv.2020) **(10)** 6 larvae (26.v.2020) **(11)** 10 larvae (27.v.2020) **(11)** 2 larvae (9.xi.2020) **(12)** 11 larvae (1.v.2020).

Platycnemidae

10. *Calicnemia eximia* (Selys, 1863)

(31) 1♂ adult (25.iv.2020)

Coenagrionidae

11. *Ceriagrion fallax* (Ris, 1914)

(31) 2♂ adult (25.vi.2020) **(37)** 1♀ adult (7.vi.2020) **(39)** 1♀ adult (7.vi.2020) **(40)** 1♂ adult (2.xi.2020).

12. Coenagrionidae sp.

(31) 13 larvae (25.iv.2020) **(31)** 32 larvae (28.xi.2020) **(36)** 1 larva (6.xi.2020) **(38)** 1♀ adult (4.x.2020) **(39)** 1♀ adult (4.x.2020).

13. *Ischnura rubilio* (Selys, 1876)

(36) 1♂ adult (6.xi.2020) **(40)** 2♂ adults (4.x.2020).

Epiophlebiidae

14. *Epiophlebia laidlawi* (Tillyard, 1921)

(19) 4 larvae (9.v.2020) **(20)** 1 larva (14.v.2020) **(21)** 1 larva (20.x.2020) **(22)** 1 larva (16.x.2020) **(23)** 1 larva (27.v.2020) **(23)** 1 larva (18.x.2020) **(24)** 3 larvae (27.v.2020) **(24)** 4 larvae (18.x.2020) **(25)** 3 larvae (29.v.2020) **(25)** 1 larva (7.x.2020) **(26)** 1 larva (30.v.2020) **(28)** 2 larvae (7.x.2020) (29) 1 larva (8.x.2020).

Aeshnidae

15. *Anax indicus* (Lieftinck, 1942)

(36) 1♂ (10.vi.2020).

16. *Anax nigrolineatus* (Fraser, 1935)

(32) 1♂ adult (6.v.2020) **(34)** 1♂ (2.xi.2020).

17. *Anax* sp.

(36) 9 larvae (6.ix.2020) **(38)** 1 larva (3.x.2020).

18. *Cephalaeschna* sp.

(18) 3♂ adult (28.x.2020) **(19)** 3 larvae (16.x.2020) **(20)** 3 larvae (20.x.2020) **(21**) 2 larvae (20.x.2020) **(22)** 1 larva (16.x.2020) **(23)** 2 larvae (18.x.2020) **(26)** 1 larva (30.v.2020) **(27)** 1 larva (9.x.2020).

19. *Cephalaeschna triadica* (Lieftinck, 1977) (identification based on superstition)

(16) 1 larva (17.v.2020) **(17)** 1 larva (28.x.2020).

20. *Polycanthagyna erythromelas* (McLachlan, 1896)

(31) 1 larva (25.iv.2020).

Gomphidae

21. cf. *Davidius* sp.

(29) 1♀ adult (5.vi.2020).

22. *Davidius* sp.1.

(7) 5 larvae (9.xi.2020) **(8)** 9 larvae (12.xi.2020) **(9)** 3 larvae (12.xi.2020) **(10)** 1 larva (8.xi.2020) **(12)** 1 larva (1.v.2020) **(12)** 3 larvae (13.xi.2020) **(19)** 3 larvae (9.v.2020) **(19)** 33 larvae (16.x.2020) **(20)** 13 larvae (14.v.2020) **(20)** 15 larvae (20.x.2020) **(21)** 11 larvae (15.v.2020) **(21)** 9 larvae (20.x.2020) **(22)** 2 larvae (24.v.2020) **(23)** 1 larva (27.v.2020) **(23)** 5 larvae (18.x.2020) **(24)** 8 larvae (27.v.2020) **(24)** 3 larvae (18.x.2020) **(25)** 14 larvae (29.v.2020) **(25)** 5 larvae (7.x.2020) **(26)** 11 larvae (30.v.2020) **(26)** 3 larvae (9.x.2020) **(27)** 1 larva (30.v.2020) **(27)** 1 larva (9.x.2020) **(28)** 7 larvae (2.vi.2020) **(28)** 12 larvae (7.x.2020) (29) 6 larvae (5.vi.2020) (29) 1 larva (8.x.2020) (30) 3 larvae (5.vi.2020) (30) 4 larvae (8.x.2020).

23. *Davidius* sp.2.

(17) 1 larva (28.x.2020) **(18)** 3 larvae (28.x.2020).

24. *Perissogomphus stevensi* (Laidlaw, 1922)

(1) 10 larvae (16.iv.2020) **(1)** 14 larvae (23.xi.2020) **(2)** 5 larvae (17.iv.2020) **(2)** 11 larvae (24.xi.2020) **(3)** 3 larvae (20.iv.2020) **(3)** 18 larvae (26.xi.2020) **(4)** 17 larvae (19.iv.2020) **(4)** 22 larvae (17.xi.2020) **(5)** 12 larvae (21.iv.2020) **(5)** 21 larva (20.xi.2020) **(6)** 14 larvae (21.iv.2020) **(6)** 11 larvae (21.xi.2020) **(7)** 13 larvae (18.v.2020) **(7)** 7 larvae (9.xi.2020) **(8)** 7 larvae (19.v.2020) **(8)** 3 larvae (12.xi.2020) **(9)** 14 larvae (19.v.2020) **(9)** 1 larva (12.xi.2020) **(10)** 10 larvae (26.v.2020) **(10)** 19 larvae (8.xi.2020) **(11)** 2 larvae (27.v.2020) **(11)** 7 larvae (9.xi.2020) **(12)** 12 larvae (1.v.2020) **(12)** 23 larvae (13.xi.2020) **(16)** 3 larvae (26.x.2020) **(17)** 4 larvae (21.v.2020) **(17)** 4 larvae (28.x.2020) **(18)** 25 larvae (21.v.2020) **(18)** 3 larvae (28.x.2020) **(19)** 3 larvae (9.v.2020) **(19)** 12 larvae (16.x.2020) **(20)** 17 larvae (14.v.2020) **(20)** 13 larvae (20.x.2020) **(21)** 6 larvae (15.v.2020) **(21)** 7 larvae (20.x.2020) **(22)** 1 larva (16.x.2020) **(36)** 1 larva (6.xi.2020).

25. Gomphidae genus indet

(1) 35 larvae (16.iv.2020) **(2)** 19 larvae (17.iv.2020) **(3)** 31 larva (20.iv.2020) **(5)** 1 larva (21.iv.2020) **(7)** 24 larvae (18.v.2020) **(8)** 5 larvae (19.v.2020) **(9)** 3 larvae (19.v.2020) **(10)** 15 larvae (26.v.2020) **(10)** 1 larva (8.xi.2020) **(11)** 15 larvae (27.v.2020) **(11)** 1 larva (9.xi.2020) **(12)** 14 larvae (1.v.2020) **(16)** 9 larvae (17.v.2020) **(16)** 1 larva (26.x.2020) **(17)** 6 larvae (21.v.2020) **(18)** 15 larvae (21.v.2020) **(26)** 1 larva (9.x.2020).

Chlorogomphidae

26. *Chlorogomphus* sp.

(9) 1 larva (19.v.2020) **(12)** 1 larva (13.xi.2020) **(16)** 6 larvae (17.v.2020) **(16)** 3 larvae (26.x.2020) **(17)** 3 larvae (21.v.2020) **(18)** 8 larvae (28.x.2020).

Cordulegastridae

27. *Anotogaster/Neallogaster* sp.

(8) 1 larva (12.xi.2020) **(12)** 1 larva (1.v.2020) **(12)** 1 larva (13.xi.2020) **(16)** 4 larvae (17.v.2020) **(17)** 5 larvae (21.v.2020) **(17)** 2 larvae (28.x.2020) **(18)** 2 larvae (21.v.2020) **(18)** 1 larva (28.x.2020) **(19)** 1 larva (9.v.2020) **(22)** 1 larva (24.v.2020) **(24)** 1 larva (27.v.2020) **(26)** 1 larva (30.v.2020).

Macromiidae

28. *Macromia moorei* (Selys, 1874)

(1) 5 larvae (16.iv.2020) **(1)** 3 larvae (23.xi.2020) **(4)** 5 larvae (19.iv.2020) **(5)** 14 larvae (21.iv.2020) **(6)** 15 larvae (21.iv.2020) **(7)** 10 larvae (18.v.2020) **(7)** 1 larva (9.xi.2020) **(8)** 5 larvae (19.v.2020) **(10)** 4 larvae (26.v.2020) **(11)** 2 larvae (27.v.2020) **(12)** 1 larva (1.v.2020) **(17)** 1 larva (28.x.2020).

Libellulidae

29. *Brachythemis contaminata* (Fabricius, 1793)

(39) 1♀ (7.vi.2020).

30. *Crocothemis* sp.

(5) 1♂ adult (21.iv.2020) **(31)** 1♂ adult (28.xi.2020) **(32)** 1♂ adult (2.xi.2020) **(32)** 1♂ adult teneral (2.xi.2020) **(34)** 1♂ teneral (2.xi.2020).

31. *Diplacodes trivialis* (Rambur, 1842)

(32) 1♂ adult (2.xi.2020).

32. *Orthetrum glaucum* (Brauer, 1865)

(1) 1♂ adult (16.iv.2020) **(7)** 1♂ adult (9.xi.2020) **(8)** 1♂ adult (12.xi.2020) **(12)** 1♂ adult (13.xi.2020) **(31)** 1♂ adult (28.xi.2020) **(39)** 2♂♂ adult (4.x.2020).

33. *Orthetrum pruinosum neglectum* (Burmeister, 1839)

(9) 1♂ adult (12.xi.2020)

34. *Orthetrum sabina* (Drury, 1773)

(37) 2♂♂ adult (2.xi.2020) **(34)** 1♂ (2.xi.2020).

35. *Orthetrum* sp.

(1) 1♀ adult (16.iv.2020) **(2)** 1♀ adult (24.xi.2020) **(2)** 1♀ adult (17.iv.2020) **(10)** 1♀ adult (26.iv.2020) **(12)** 1♀ adult (13.xi.2020) **(31)** 46 larvae (25.iv.2020) **(31)** 17 larvae (28.xi.2020) **(36)** 1 larva (6.xi.2020).

36. Orthetrum triangulare (Selys, 1878)

(1) 2♂♂ adults (16.iv.2020) **(2)** 1♂ adult (17.iv.2020) **(4)** 1♂ adult (19.iv.2020) **(5)** 1♂ adult (21.iv.2020) **(8)** 2♂♂ adults (19.v.2020) **(9)** 2♂♂ adults (12.xi.2020) **(13)** 1♂ adult (28.iv.2020) **(31)** 1♂ adult (28.xi.2020) **(31)** 1♂ adult (25.iv.2020) **(32)** 1♂ adult (2.xi.2020) **(32)** 3♂♂ adults (4.v.2020) **(34)** 1♂ adult (2.xi.2020) **(35)** 1♂ adult (4.v.2020).

37. *Palpopleura sexmaculata* (Selys, 1878)

(32) 1♂ adult (2.xi.2020).

38. *Pantala flavescens* (Fabricius, 1798)

(5) 1♂ adult (21.iv.2020) **(10)** 1♂ adult (24.iv.2020).

39. *Sympetrum fonscolombii* (Selys, 1840)

(1) 1♂ adult (16.iv.2020) **(36)** 14 larvae (10.vi.2020) **(36)** 1 larva (6.xi.2020) **(37)** 1♂ adult (4.x.2020) **(38)** 5 larvae (3.x.2020) **(39)** 1♂ adult (4.x.2020) **(40)** 1♂ adult (4.x.2020).

40. *Sympetrum hypomelas* (Selys, 1884)

(36) 1♂ adult (6.xi.2020) **(37)** 1♂, 1♀ adults (4.x.2020) **(40)** 1♂ adult (4.x.2020).

41. *Sympetrum* sp.

(37) 1 larva (3.x.2020).

42. *Tramea virginea* (Rambur, 1842)

(36) 1♂ adult (6.xi.2020).

43. *Tramea* sp.

(36) 4 larvae (6.xi.2020).

44. *Trithemis aurora* (Burmeister, 1839)

(12) 1♂ adult (13.xi.2020) **(31)** 1♂ adult (28.xi.2020) **(39)** 1♂ adult (7.vi.2020) **(32)** 2♂♂ adult (4.v.2020).

45. *Trithemis festiva* (Rambur, 1842)

(5) 1♂ adult (21.iv.2020).

46. *Zyxomma* sp.

(37) 3 larvae (3.x.2020).

Discussion

Most of the specimens collected as adults are common and wide spread species and most of them are species breeding at standing water. As no fieldwork could be conducted

from mid-June to the end of September due to Covid the list of species observed as adult is incomplete and gives little information on the composition of the fauna.

The larvae found at the 10 standing water sites are all of common and widespread species. Exception to this is the discovery of three larvae of *Zyxomma* at site 33. This genus is new to Bhutan although its presence was expected as it is common in India. Surprisingly however is the elevation (1236 m), at which the larvae were found. It may be that these larvae are the offspring of a dispersing female ovipositing there in spring 2020 as a population with larva surviving the winter at this elevation seems unlikely. Corbet (1962) refers to a personal communication by Lieftinck stating that *Zyxomma petiolatum* has a larval development of about 180 days, indicating that a time line in which oviposition took place early spring and nearly full-grown larvae are found in late autumn is possible.

The most interesting data are those of the larva collected at running waters. The larvae found at running waters all belong to taxa with relatively small ranges, most of them largely confined to the Himalayan region with *Neurobasis chinensis* being the only wide-ranging species. Figure 10 gives a visual summary of the larval composition of the 27 sites where larvae were collected (sites 13-15 were dry during sampling and no larvae were collected). The first thing it shows is that each of the three sites belonging to one sampling stretch at a stream (L1-L10) in most cases strongly resembles each other. The number of larvae collected at each site range from 3 to 71. The average number of larva and the average number of species found at each site vary between elevation with an average of 49 larvae found in the range between 0-1000 m; 56 larvae found in the range between 1000-2000 m and 16 larvae found in the range between 2000-3000 m. Probably it is mainly the colder temperatures resulting in a lower number of larvae at higher altitudes.

The figure also shows that not only the number of larvae and number of species change with altitude but also the composition of the fauna changes. The three commonest species are three species of Gomphidae: *Perissogomphus stevensi* (375 specimens), Gomphidae genus indet spec (196 specimens) and *Davidius* spec1 (193 specimens). All the 196 larvae of Gomphidae genus indet spec are found between 509-1661 m and all the 375 larvae of *Perissogomphus stevensi* are found between 509-2250 m. In contrast all the 193 larvae of *Davidius* spec1 are found between 931-2958 m with 160 of these found above 1934 m. *Epiophlebia laidlawi* is one of the three species of the suborder Epiophlebiidae. In the last decade a series of papers appeared which showed that larvae are common in large parts of Bhutan (e.g. Brockhaus & Hartmann, 2009; Nidup et al. 2020). We found it at ten localities between 1934 and 2778 m a.s.l. Surprisingly not a single observation of its adult is known from Bhutan although one record from 9 May 2017 pertains to specimen died within its larval skin during emerging (Observation.org). Davies (1992) encountered adults of *E. laidlawi* away from water at two mountaintops in Darjeeling, one of which was dense bamboo forest at 11.000 ft (3.350 m). Based on this it seems likely that adults *E. laidlawi* move away from their breeding habitat and can be found slightly higher up but records of this from Bhutan are still wanting.

Figure 10. Composition of the larval community of odonates in running water at different altitudes. The x-axis shows the altitude and the total number of larvae caught at the locality in brackets.

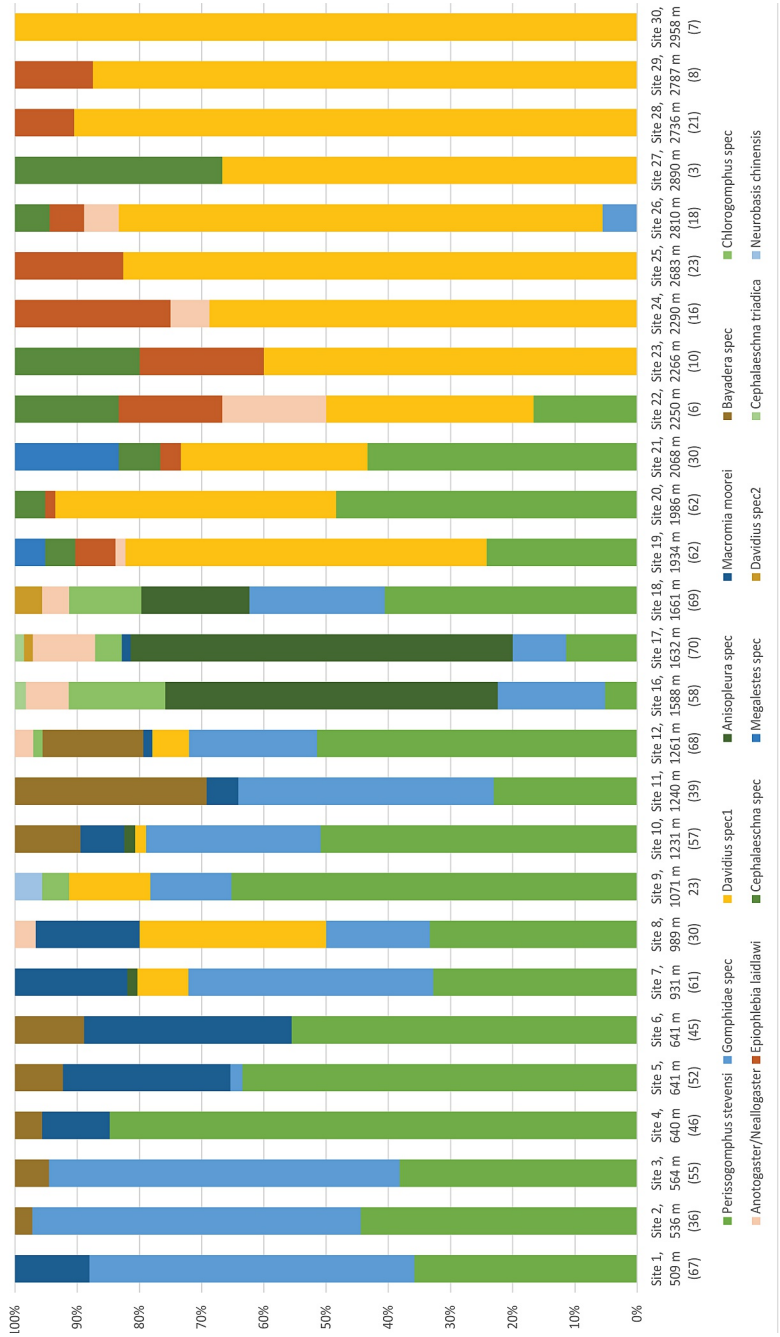
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Site 1, 509 m (67)
Site 2, 536 m (36)
Site 3, 564 m (55)
Site 4, 640 m (46)
Site 5, 641 m (52)
Site 6, 641 m (45)
Site 7, 931 m (61)
Site 8, 989 m (30)
Site 9, 1071 m 23)
Site 10, 1231 m (57)
Site 11, 1240 m (39)
Site 12, 1261 m (68)
Site 16, 1588 m (58)
Site 17, 1632 m (70)
Site 18, 1661 m (69)
Site 19, 1934 m (62)
Site 20, 1986 m (62)
Site 21, 2068 m (30)
Site 22, 2250 m (6)
Site 23, 2266 m (10)
Site 24, 2290 m (16)
Site 25, 2683 m (23)
Site 26, 2810 m (18)
Site 27, 2890 m (3)
Site 28, 2736 m (21)
Site 29, 2787 m (8)
Site 30, 2958 m (7)
Perissogomphus stevensi
Anotogaster/Neallogaster
Gomphidae spec
Epiophlebia laidlawi
Davidius spec1
Cephalaeschna spec
Anisopleura spec
Megalestes spec
Macromia moorei
Davidius spec2
Bayadera spec
Cephalaeschna triadica
Chlorogomphus spec
Neurobasis chinensis

Table 1 shows the number of larvae collected at the sites with running water in the pre- and post-monsoon period. Of the 1058 larva a total of 654 (61.9%) were collected in the pre-monsoon period and 404 (38.1%) in the post-monsoon period. This difference

Table 1. Number of larvae collected in the pre-monsoon and in the post-monsoon period. Species with more than 10 larvae collected and over 60% of the collected larvae confined to one of the periods are shown in green.

Family	Species	Larvae pre-monsoon	Larvae post-monsoon	Premon-soon %	Postmon-soon %
Synlestidae	*Megalestes* spec	5	3	62,5	37,5
Calopterygidae	*Neurobasis chinensis*	1	0	100	0
Euphaeidae	*Anisopleura* spec	60	30	66,7	33,3
Euphaeidae	*Bayadera* spec	40	4	90,9	9,1
Epiophlebidae	*Epiophlebia laidlawi*	13	11	54,2	45,8
Aeshnidae	*Cephalaeschna* spec	1	12	7,7	92,3
Aeshnidae	*Cephalaeschna triadica*	1	1	50	50
Cordulegastridae	*Anotogaster*/*Neallogaster* spec	16	5	76,2	23,8
Chlorogomphidae	*Chlorogomphus* spec	10	12	45,4	64,6
Gomphidae	*Davidius* spec1	81	112	42	58
Gomphidae	*Davidius* spec2	0	4	0	100
Gomphidae	Gomphidae spec	192	4	98	2
Gomphidae	*Perissogomphus stevensi*	173	201	46,4	53,6
Macromiidae	*Macromia moorei*	61	5	92,4	7,6
TOTAL		**654**	**404**	**61,9**	**38,1**

can either be due to a lower number of larvae in the water in the post-monsoon period or can be caused by the higher water flow making it more difficult to find larvae. In six species of which at least 10 larvae were collected 60% or more of the larvae were collected in either the pre-monsoon period (*Anisopleura* spec, *Bayadera* spec, *Anotogaster/Neallogaster* spec, Gomphidae spec, *Macromia moorei*) or the post-monsoon period (*Cephalaeschna* spec). Some of the differences between the two periods are very pronounced but interpretation is not straightforward. For instance, 61 of the 66 larvae of *Macromia* were caught in the pre-monsoon period but these were of different sizes suggesting that the species spends several years in the water before emerging which would suggest that the low abundance of larvae in autumn is caused by the larvae being more difficult to catch due to a higher water table. The relatively high number of larvae of *Bayadera* and *Anisopleura* could be caused by these species emerging in May to July resulting in the larger sized classes being less common in autumn. The only species being more common as larva in autumn is *Cephalaeschna* (12 of 13 larvae caught in the post-monsoon period). This is slightly surprising as the species of *Cephalaeschna* are all autumn species. Due to this one would expect that a part of the larvae already had emerged at the time the sampling was conducted resulting in a lower number of larvae in the post-monsoon period instead of the observed higher number. A possible explanation is that the larvae of *Cephalaeschna* are still small in spring and are easily missed but this explanation only holds when the larvae of this genus spend only one year in the water as larvae, which seems unlikely for a species of Aeshnidae living in cold, running water.

Conclusion

The results show clearly that the number of larvae and number of species differs strongly between different elevations, and that the number of larvae and species rapidly decreases above 2000 m. None of the species of running water is common throughout the whole range from 500 to 3000 m although some have an altitudinal range stretching across 1500 m. Sampling in the pre- or the post-monsoon clearly has influence on the number of larvae found with at least six of the 14 taxa showing clear differences between sampling period, five of them being most common in the pre-monsoon. This shows that when monitoring habitats based on larval dragonflies it is important to compare data collected at similar periods of the year. It is interesting to compare the results with those of the Mahato & Edds (1993) who collected larvae at 40 sites at the Gandaki river in central Nepal slightly over 600 km to the west of our research area. Their sites were between 50 and 1189 m a.s.l. with one site at 2560 m a.s.l. Relatively many of their sites were from the lowland, with 14 of their 40 sites lower than our lowest (509 m a.s.l.) site. Although no habitat descriptions are given the species they encountered suggest that these lower sites had a relatively slow current, maybe even with largely stagnant sections, resulting in the presence of species of Coenagrionidae and Libellulidae normally associated with standing water (*Pseudagrion rubriceps* Selys, 1876, *Brachythemis contaminata, Crocothemis servilia*, or waters with a moderate current (*Trithemis festiva, Orthetrum taeniolatum* (Schneider, 1845), *O. pruinosum*). However, like in our study the bulk of the specimens consist of *Macromia moorei* (103 specimens) and four species of Gomphidae (713 specimens). Two of these species of Gomphidae were not found by us: *Burmagomphus* spec. and *Paragomphus lineatus* (Selys, 1850) (respectively 14 and 32 specimens) the latter probably simply because it occurs at more sluggish habitats in lower areas which were not sampled by us. By far the commonest species Mahato & Edds (1993) encountered were *Davidius* spec (480 specimens) and *Anisogomphus occipitalis* (Selys, 1854) (187 specimens). The later was not found by us although our Gomphidae spec might be this species. Also, in our study *Davidius* was among the most common taxa encountered, sharply contrasting with the small numbers of observations of adults available for this genus. Remarkably Mahato & Edds (1993) did not record *Perissogomphus stevensi* which was with 375 specimens in our study the most common species. This seems to be a difference caused by geographical distance.

In 2021 a river system 60 km to the east of our study sites will be sampled for odonate larvae over an even slightly wider altitudinal range. This will make it possible to compare the results of two river systems with relatively little impact of geographic distance. These data will give a good indication if the differences observed by us between post- and pre-monsoon are an annual pattern and not merely based on the specific circumstances of 2020. It will also give some insight in the extent in which the different river systems found have a comparable faunal composition.

Acknowledgements

The field work of this study was made possible due to a grant of the National Geographic Society (NGS-72271C-20) for the project ‘Project Title: Exploring the invertebrate diversity of the last virgin rivers of Bhutan, the Eastern Himalayan’. The master thesis of

the first author was made possible due to a grant of the National Biodiversity Center - Naturalis, the Netherlands and a grant from a generous private donor. We are gratefull for the review of the paper by Albert Orr, Thomas Brockhaus and Martin Schorr.

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